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IN-BUILDING DISTRIBUTION OF PACKET RADIO SIGNALS

1.0 INTRODUCTION

This note is concerned with the dual problem of getting a packet radio signal into a building and distributing the signal throughout the building. This note may be premature in that the problem is several system development steps away at this point in time. The importance of looking at it now is that this shallow investigation indicates that the signal strength environment on a city street will probably need to be 25 to 30 db higher than that previously considered if direct radiation into buildings is to be considered (i.e. no building distribution system employing amplification). This is quite unattractive since this implies either excessive transmit power and/or quite close repeater spacing.

There are two ways a packet radio signal can be delivered to a terminal inside a building. It can be radiated through the building walls or it can be conducted through. Of course, radiation is by far the simplest mode and will be used whenever it provides a sufficiently strong signal to the terminal. The conduction mode requires wiring the building with some special lines or making special use of wires already present.

Several articles have appeared in the literature which address the approach of radiating into buildings. At least two more are in process; one by the F.C.C. and another by the British Post Office. These data must be used with some caution for packet radio system design since most

testing has been relative to voice or low data rate transmission systems that are relatively tolerent to signal distortions resulting from multipath. The multipath or signal dispersion problem is expected to be far more critical for packet radio systems operating at data rates in the range of 100 kb/s.

Little of the published material regarding the wire transmission of data signals is applicable to the packet radio situation. The Bell System has an extensive background on data and digitized voice transmission. However, Bell is concerned with transmission over much longer paths than the in-building distances considered here. Other applications are related to point-to-point transmission as between computers located in the same building. High grade coaxial cables solve that problem nicely, but this answer would probably be prohibitively expensive for the packet radio scenario of general distribution throughout every important building in the U.S.

2.0 RADIATION INTO BUILDINGS

Radio waves suffer little loss at VHF frequencies as they pass through dielectric type walls such as wood, glass or drywall construction. Some loss data is shown in Table 1 for conducting walls ("Semi conducting" might be a more accurate term) at a frequency of 160 MHz.

TABLE I

ATTENUATION AT 160 MHZ[2]

Wall Material	Transmission Loss
8 inch Concrete Block	5-8 db
6 inch Solid Concrete without Steel Reinforcing	10-15 db
Suspended Metal Ceiling	15-20 db
Solid Metal Walls	20-40 db
Right Angle Bends in Hallways	15-20 db

Statistical building penetration measurements have been made at 35 MHz, 150 MHz, 450 MHz and 910 MHz. [1., 2., 3.] In general, these measurements were made by illuminating a building from a sufficient distance such that the field strength is uniform outside the building along one wall. Measurements were then made inside the building in interior rooms - not in rooms on the illuminated side of the building. Of course, within a room, many standing waves exist. Maximums occur at intervals of approximately one-half wavelength in all three planes, interspersed with nulls in the field. The maximums tend to be quite steady in amplitude but the minimums vary in level due to people moving around in the building - even in adjacent rooms and hallways.

Results of these measurements were stated as excess loss, or the loss accrued due to penetration of the building:

TABLE II

BUILDING PENETRATION BY RADIATION, 35 MHz-910 MHz

1% of measurements, excess loss was less than 7 db
50% of measurements, excess loss was less than 29 db
99% of measurements, excess loss was less than 35 db

These measurements are valid for floors above ground. Signals measured in first-level basements are 18 to 30 db below ground floor signal levels.

Variation of excess loss with frequency is inconclusive from the data. 900 MHz measurements were markedly better than 450 MHz signals in some rooms - but were worse in others. Rice[1.] stated that 150 MHz was slightly better than 35 MHz. However, Schefer[3.] was not able to corroborate Rice's findings.

Radio waves apparently enter buildings by two mechanisms. At low frequencies, the radiation penetrates the dielectric type walls. At higher frequencies where the windows are larger than a half-wave length, the radiation comes in through the windows. These statements are intuitive and one might be led to believe that somewhere between good wall penetration at 35 MHz and good window penetration at microwave frequencies, there might be

a frequency in between that would display statistically poorer results than the ends of the spectrum under discussion. Some of the writers of these articles agreed at a recent conference in Boulder[3]. that one frequency is not significantly better, worse, or even different from another from a statistical viewpoint.

If a distant transmitter does not deliver a sufficient signal into a particular building, a possible solution is to locate a repeater on a nearby building to provide a stronger illumination. This technique was applied to a 30 story hotel building[2]; the repeater was on a 9 story building nearby. It is reported to have worked well, even into the basement and in the elevators.

3.0 SIGNAL CONDUCTION INTO BUILDINGS

Conducting signals into buildings would probably furnish stronger, more reliable signals at the cost of physically wiring the building itself for this special purpose. Of course, this presupposes that a two-way repeater is situated on top of the building. It must receive the signal from outside and send it inside the building; it must also receive the signal off the wire from inside the building and transmit it to the rest of the world. For the conductors themselves, one must consider the use of existing wiring, telephone or power wiring. If these are not suitable, a balanced transmission line might be used as suggested by Farmer, et.al.[2].

The repeater must receive some special attention. It might receive and re-transmit rf if the in-building distribution wiring is capable of carrying the rf. On the other hand, the repeater might be required to receive an rf signal, down-convert to a carrier signal, and vice-versa. If the repeater sends and receives rf it will probably be simply an amplifier.

If the wiring will not handle the rf, then the repeater must receive an rf signal and down-convert to a low frequency carrier for transmission into the building. An additional box would be required at the terminal, then, to translate back up to rf so the terminal could receive the data. Alternatively, the terminal might have a carrier frequency input-output

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mode for such operation. Only a patch cord to connect the terminal to the building wiring would then be required.

3.1 Telephone Lines

If a suitable terminal device is available, the telephone lines are quite capable of carrying a high data rate at carrier frequencies. It should be pointed out that F.C.C. tariff No. 260 makes provisions for connecting company-owned in-plant terminals and wiring to the telephone industry's outside-plant transmission and switching network. In other words, it is possible for a company to own its own telephone equipment inside the company facilities. To avoid the problem of what the telephone industry will allow, the discussion which follows assumes that the in-plant telephone system is privately owned and that it meets the telephone industry requirements at the interface between private terminals and the telephone industry's transmission and switching equipment.

Telephone lines inside a building consist of twisted pairs of #20 to #26 wire. These are bundled into cables and passed throuch conduits to terminal blocks and switchboards. The Bell System uses such lines for its T-1 carrier system.

The T-1 carrier system digitizes 24 voice channels at an 8 khz sampling rate and processes them into a time division multiplexed signal at 1.544 megabits per second. This digital signal is transmitted over twisted pairs with regenerative repeaters located typically every 6000 feet. This distance is determined primarily by the frequency response of the line; that is, the attenuation and group delay as a function of frequency. Lines used are toll grade cable; hence distance between repeaters is considerably greater than would be possible with in-building wiring where cable of 22 to 26 wires is typical. Just before the pulses are lost to distortion, a repeater is installed which detects the distorted pulse, regenerates a clean new pulse, and sends it on toward the next repeater.

If the telephone industry can send 1.544 megabits per second on these lines, then it seems reasonable that packet radio signals of one to a few hundred kilobits per second on a carrier of a few hundred kilohertz can

also be sent on these lines. In-building distances would certainly be less than 6000 feet. Signal levels should be held to the range of Odbm to -10 dbm. Higher levels increase the risk of crosstalk onto other lines which might not get filtered before they leave the premises. Table III shows the maximum signal levels at the telephone company interface located on the premises. The packet radio signals must be filtered out before they reach that interface.

TABLE III

MAX. APPLIED SIGNAL LEVELS TO 600 OHM VOICE PRIVATE LINES

300 - 3000 Hz*	-29 dbm 3 second average. Measurement methods prescribed by Bell System.
3995 to 4005 Hz	-47 dbm
4000 Hz to 10000 Hz	-32 dbm
10000 Hz to 25000 Hz	-40 dbm
25000 Hz to 40000 Hz	-52 dbm
40000 Hz up	-66 dbm

*2600 Hz must be blocked by user equipment. At no time shall energy appear solely between 2450 and 2750 Hz. When power is applied in that band, it shall not exceed the power currently present in the 800 to 2450 Hz band.

The telephone distribution wiring inside a building is a poor vehicle at rf frequencies because it is small and non-uniform as a transmission line causing high loss, as much as 2db/ft at 3 GHz.

3.2 Power Wiring

Another vehicle which might be considered for conductive in-building distribution of packet radio signals is the power wiring. Measurements were made by the writer on a sample of typical commercial power wiring. It was 40 feet long, 3/4 inch thin wall conduit with 3 No. 10 wires pulled through. The wires were individually insulated with polyvinylchloride insulation. Two of the three wires were grounded to the conduit; the third

was the conductor in an unbalanced configuration. The impedance of the line was nominally 55 ohms with a VSWR of 1.5 to one over a frequency range from 400 MHz to 4 GHz. Of course, the line is non-uniform so the impedance changes with frequency. A good reason for the line having such a low VSWR is because it is so lossy. Loss measurements are shown in Table 4.

TABLE IV

POWER LINE ATTENUATION AT MICROWAVE FREQUENCIES

Freq. (GHz)	Attenuation (db/100 ft)
.4	62.5
1.0	80
2.0	100
3.0	115

By comparison, RG-8/U coaxial cable has 16 db/100 ft attenuation at 3 GHz, RG-58/U has 37.5 db/100 ft, and commercial T.V. 300 ohm flat twin lead has 7.6 db/100 feet at 3 GHz. Needless to say, the power wiring is quite lossy at microwave frequencies. However, it is universally installed in buildings and can be used with very simple couplers between any ordinary outlet and a packet radio on one end and an outlet and the roof-mounted receiver on the other end. After all, we are working with a transmitter and receiver that expect over 100 db of transmission loss between them. On the other hand, one can radiate signals inside a typical building with less loss unless he has to penetrate metal walls.

The power wiring can handle low frequency carrier signals, probably with less loss than the telephone lines discussed previously. However, the noise generated by ac appliances can be both quite high and quite variable. It would be necessary to conduct an extensive measurement program on the power distribution wiring before attempting to design a data system that used it for transmission.

3.3 Special Wiring

Buildings and tunnels have been successfully wired to distribute radio signals using balanced transmission line as the conductor. Balanced

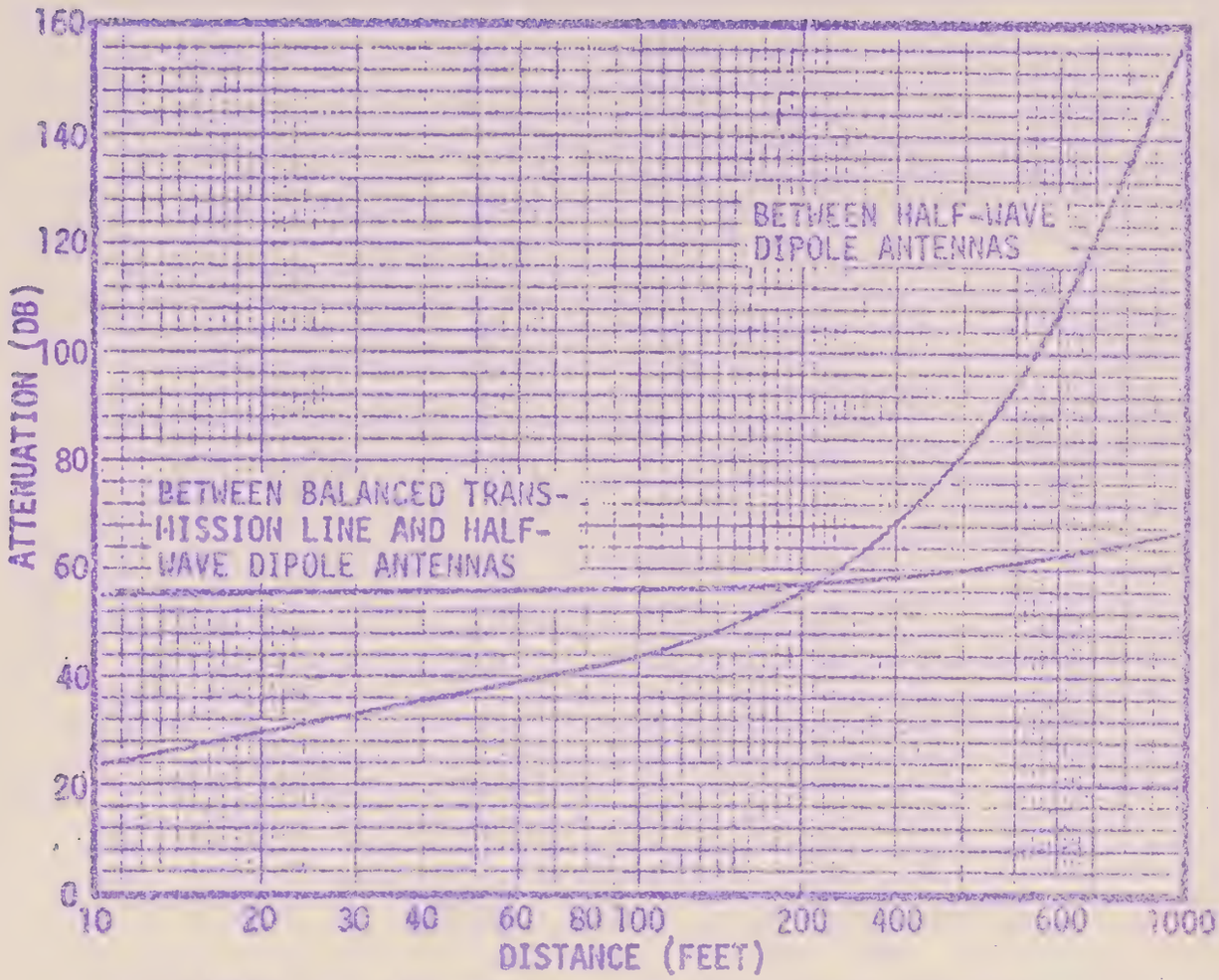

FIGURE 1. Attenuation in Tunnels and Buildings Between Half-Wave Dipoles and Between Balanced Transmission line and Half-Wave Dipole at 160 MHz.

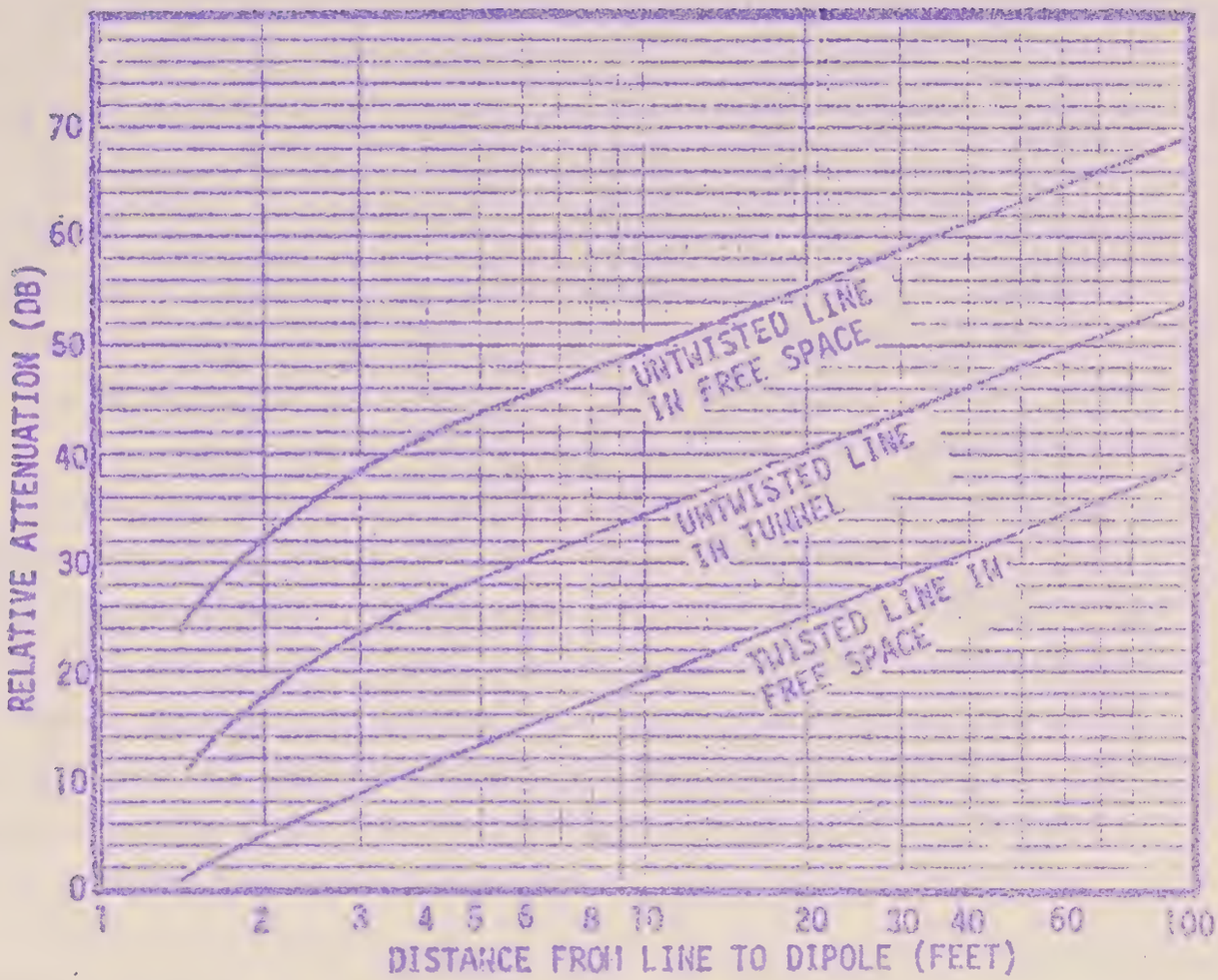

FIGURE 2. Relative Attenuation Between 200 Ohm Balanced Transmission Line and Half-Wave Dipole Antenna at 160 MHz.

open wire transmission line such as TV twin lead is not a perfect transmission line in that it does radiate some of the signal it carries; it leaks. The power lost to leakage is considerably less than the I^2R loss so it is a good transmission line. But we can use this leakage to our advantage. A roof-mounted repeater might receive a signal from the outside world, amplify it, and send it into a many-branched twin lead transmission line, each branch being terminated at the far end. The twin lead is installed near the ceilings of the hallways of the building, in the ceilings if they are of sheetrock or acoustical tile construction. These lines radiate a small signal along their length which is quite steady and strong enough for a packet radio terminal to receive on its regular antenna.

The curves of Figures 1 and 2 are taken from Farmer, et. al[2] and were measured at 160 MHz. However, the radiation from a particular line increases with the square of the frequency. An increase in the leakage of the line is desirable in our peculiar use of the line. This can be achieved by twisting the line tightly, on the order 1/4 twist per line spacing as measured along the line. Figure 2 shows a 30 db increase in radiation achieved by twisting the line.

3.4 CATV

Television cable systems are being considered by the packst radio team for distributing the packet radio signals throughout cities as well as inside buildings within the city. Since CATV is receiving more concentrated study elsewhere, the writer considers it outside the scope of this note. However, where such cables exist, they do offer an attractive solution to the in-building distribution problem.

4.0 CONCLUSIONS

Every building will require some analysis to determine which technique is required to deliver a useable signal to a terminal inside. If the building has windows and is relatively close to a system repeater, no special techniques will be required. At greater distances, a simple

repeater with directional antennas focused on specific buildings will deliver the signals to interior users by radiation. Buildings which are effectively shielded must have a simple, dedicated repeater to receive a signal and pipe it into the building over conductors of one type or another. Of the three conductor types considered here, the twin lead system appears to be the most attractive as the line is cheap and it requires no increased complexity of the terminal circuitry over that required for out-of-doors use.

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